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Estimating solid contaminant levels in beach sands through petrographic analysis, screening evaluation, and optical imaging

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Abstract: Determining the level of solid pollution in beach sands located near artificial inland water bodies in order to maintain high safety standards is a difficult and expensive task. The tests aimed at determining beach pollution caused by solid wastes through analysis of toxic and chemical concentrations, are time-consuming and usually require several days before the results are available. In addition, the maintenance of the beach area involving beach raking or grooming, and the seasonal replenishment of sand makes it difficult to realistically determine the chemical or bacterial contamination of the tested material. Solid pollutants, such as glass, caps, cans, thick foil, metal, and plastic fragments, pose a greater health risk to beachgoers. The above-mentioned pollutants, especially small ones, are hardly visible on the surface or they are buried at shallow depths. Beach garbage poses a serious threat that can lead to infections from cuts and scratches. These injuries can become infected, further jeopardizing the health and lives of beachgoers due to risks like tetanus, staphylococcus, etc. The authors presented a new petrographic method aimed at assessing the quality of sand by examining the content of solid pollutants. The obtained results allowed us to conclude that the mentioned procedure can be used for a quick quantitative estimation of the content of potentially dangerous and undesirable pollutants in beach sands. Consequently, the method implemented to determent the amount of solid pollutants in beach sands has proven to be a valuable tool for recreational facility administrators, helping them in taking necessary measures to ensure the safety of beach users. Petrographic analysis of beach sands revealed the presence of pollutants of plant origin (0.4–1.8%), plastic (0.1–0.4%), paper (0.1–0.6%), charcoal (0.1–0.5%), glass (0.1–0.4%), metals (0.1–0.4%), rust (0.1–0.3%), ash and slag (0.1–0.3%), and fossil coals (0.1–0.2%).

Introduction

An important aspect of the activities carried out by recreational and leisure centers with access to water bodies is the operation of swimming pools (Holman and Bennett.1973). Most natural and artificial bathing sites have beaches, and the shores are usually sandy (Stachowski et al. 2018). The Beach sands of recreational areas, specifically reservoirs used for recreational purposes, are sourced from quartzite mines. This specially selected material is fitted with a geotextile backing that is produced using modern technology. This prevents the overburden from mixing with the substrate and enables rainwater infiltration into the sand layer. Both natural and artificial beaches used for recreational purposes are subject to environmental degradation through the application of various types of pollutants (Li and Zhang 1987). This process can occur through unintentional factors like rains, watercourses, wave action, etc., as well as intentional factors such as dumping of garbage, waste, fecal matter, etc.) by humans or domestic animals. The act of littering on beaches results in irreversible chemical, biological, and mechanical hazards for beach users. Assessing the quality of beach sands and adjacent water bodies in terms of chemical or bacterial contamination is a commonly used method that shows possible health risks for users of leisure facilities (Claisse 1989). Microorganisms, such as bacteria, fungi, and parasites are a permanent component of beach sands. Through numerous studies conducted on sandy coastal recreation sites, it has been discovered that fecal bacterial populations and various strains of anerobic mesophilic microorganisms can endure in the sands (Halliday and Gast 2011). According to the latest WHO guidelines, the primary cause of contamination of beach sands with dermatophyte strains is animal feces, mainly from dogs and horses. The dermatophytes can contribute to the development of fungal diseases in humans that originate from animals (WHO 2021).

In particular, streptococci and Enterobacteriaceae may cause urinary and digestive disorders in immunocompromised patients (Şanlıtürk and Güran 2021). The expansion of fungi is usually associated with a higher content of undecomposed organic matter in the sands; they are represented in large numbers by dermatophytes, organisms that cause mycoses of the skin, hair and nails (Sabino et al. 2014). Most pathogens enter the human body through the respiratory or digestive system.; Fortunately, these organs are equipped with a defense system in the form of mucous membranes, which capture most of the harmful antigens (Działo et al. 2010). However, direct infections resulting from pathogens that penetrate through the skin (abrasions, scratches, wounds) can be much more dangerous (Spichler-Moffarah et al. 2016). A potentially dangerous infection may occur when an open wound comes into direct contact with harmful bacteria. Skin injuries can allow pathogenic bacteria and viruses to enter the body, facilitating the development of external infections due to microorganisms present in water reservoirs (Tomenchok et al. 2020). This may lead to diseases caused by organisms and microbes commonly considered as harmless (McLaughlin 2017, Marina and Popa 2020). To minimize health hazards on beaches, sands are tested for the presence of chemical and biological waste. The quantity and quality of solid waste, including metals, plastics, wood, and more, are not determined through research methods and tools; instead, they are assessed based on surface observations. It is suggested that occasional beach raking or grooming is sufficient to keep beach sands clean and to ensure the safety of beachgoers (García-Morales et al. 2018). This assumption is contradicted by the frequent occurrence of minor injuries, or less commonly, deeper injuries among beachgoers due to contact with small sharp elements (Moran and Webber 2020).

Despite the efforts and financial expenses undertaken by beach administrators, no cost-effective and efficient method for detecting as assessing hazardous solids in beach sands has been developed so far. (Cesia et al. 2020, Zielinski et al. 2019). The unassessed and unmonitored deposition of solid waste on the beaches, in addition to the danger to beachgoers mentioned earlier, can lead to pollution in nearby water bodies. Both precipitation and watercourses infiltrating beach sands can carry undesirable chemical and solid elements to bathing areas. (Wufuer et al. 2021). Even small pieces of glass, charcoal, plastics, and biomass splinters accumulating in water reservoirs pose a significant risk of causing minor injuries that can consequently lead to more serious infections among beachgoers (WHO 2003).

Moreover, plastic degrades very slowly, accumulating in water systems over time (Wulai et al. 2020). It is important to note that garbage left on inland beaches comprises accumulated waste materials, typically discarded by visitors or washed ashore from other locations. This litter can include various items, such as plastic bottles, food wrappers, cigarette butts, paper products, fishing gear, and other non-biodegradable materials. The extent and composition of the garbage can vary depending on factors like beach popularity, nearby urbanization, and waste management practices. All these factors make it difficult to accurately quantify the persistent waste present in beach sands (Nowak 2019).

Methodology

Research object

Beach sands located in the coastal zone of the "Sosina" artificial water reservoir located in Jaworzno, southern Poland, were subjected to an analysis (Fig. 1). The water reservoir was formed through quartzite sand mining on the site of the former "Szczakowa" backfilling sand mine. In the 1970s, the excavation area was filled with water, and its maximum depth now fluctuates around 2.5 m (Rzętała 2008).

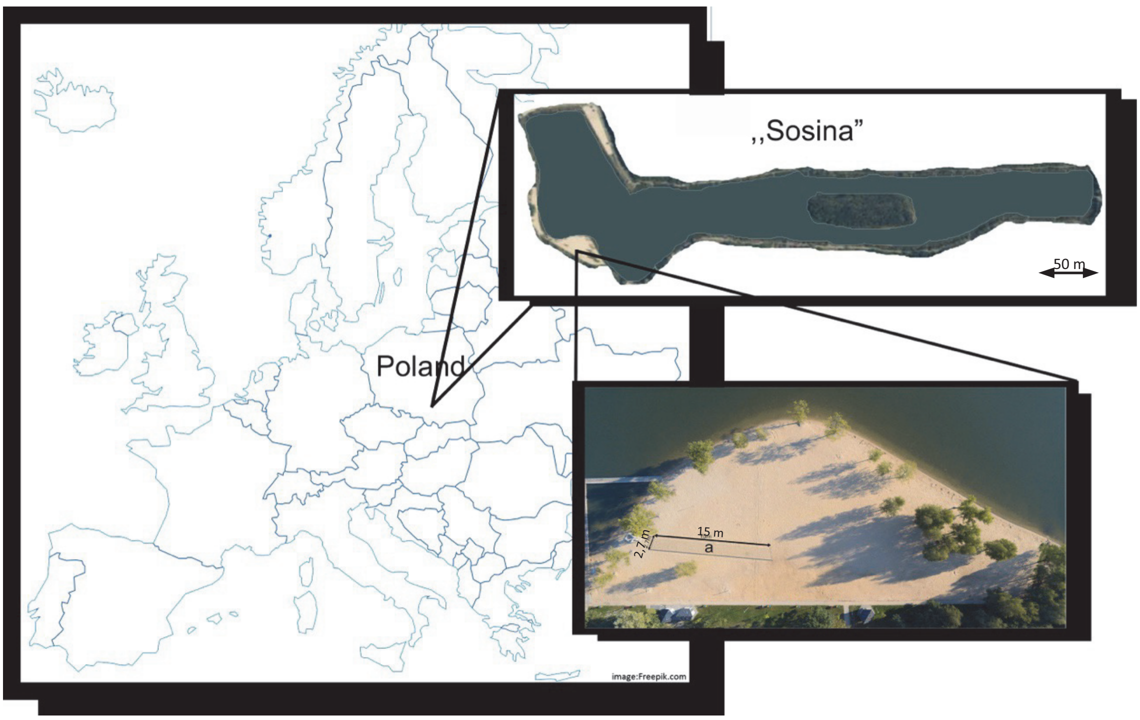


Fig. 1. Location of the study subject (EPSG:3857 system 50°14'22.8 "N 19°19'41.2 "E), (a) location of the study area on the beach at the,,Sosina" reservoir

The beach was made by spreading sand sourced from the Maczki-Bór mine (Frolik et al. 2007) on a sandy soil reinforced with geotextile layer. The geotextile backing material ensures water permeability and prevents different soil fractions from migrating between the basement (soil) and the overburden (sand). The upper beach layer was created using sand obtained from a production plant specializing bulk materials. Prior to usage, the sand was cleaned in an industrial mechanical separator and sieved to a grain fraction of 0.1 to 0.4 mm. The upper beach layer was evenly spread across the entire surface, creating a covering with a thickness of 16 to 20 cm. This work was carried out during the winter months of 2020 on the sandy shore in question. In June 2021, the beach was open to the public, marking the beginning of its use. Consequently, in September 2021, a decision was made to analyze a section of the beach sands to determine the possible presence of solid waste. It should be noted that the testing area, measuring 15 meters in length and 2.7 meters in width (Fig. 1) had not undergone any mechanical or manual cleaning since the new sand was laid until the start of the study.

Petrographic analysis of beach sand

The first sand sample (sample No. 0) for petrographic analysis was collected in November 2020 from freshly created sand piles brought to the beach area to be spread on the beach surface (Fig. 2).

Petrographic sampling work continued after the swimming season in September 2021. This involved defining the study area and identifying sampling points (Fig. 3a). Nine sand samples were collected from the designated rectangle using a 20×15×20cm sampling tool (Fig. 3b). This allowed for obtaining approximately 600 g of test material from each individual site each time. The samples were collected from designated points within the test rectangle, with each point situated at intervals of 3.75 meters. These points were chosen from three rectangular fields, each measuring 0.9 m × 15 m (Fig. 3a). Then, the individual samples were ground in a ball mill to obtain a fraction of 0.1 cm. Next, each sample was passed through a set of 0.1 cm and 0.05 cm sieves and a random sand sample of approximately 15g was collected from a 0.05 cm sieve with a measuring cup. The collected sample was placed in a 4 cm diameter spatula and cold-mounted in Struers' SpeciFix-20 Kit resin. After the resin had solidified, the sample was sanded using waterproof sandpaper with grit sizes of 800, 1200 and, finally, 4000. This process aimed to eliminate excess resin and create a level surface for the sample. The final step involved polishing the sample on a wheel covered with cloth made from woven natural silk. The resulting polished sections (Fig. 3 c, d) were treated with an ultrasonic bath and then subjected to microscopic observation under white reflected light and oil immersion. To observe and determine the qualitative and volumetric composition, a ZEISS Axio Imager M2m polarized optical microscope with a 75×50 scanning stage and MCW-2 ECO control panel was used. The method used was oil-immersion observation of the polished sections (ISO 8036, 2015) at 500X magnification. While the sample was being automatically shifted (every 50 μm), 1000 measurements were conducted by individually counting each identified component using the eyepiece graticule. The volume-quality composition was automatically calculated through dedicated software (Labikon) designed for the above-mentioned scanning stage.

Optical imaging of beach sand surface

The Yuneec H520 flying laboratory, equipped with the E90 camera, was used for the estimation of the amount of residual solid waste and its identification. This assessment aimed to test the suitability of this type of device for assessing waste deposition on beaches. The conducted observation can be further compared to visual attempts made by recreational facilities employees to estimate littering of beach sandsof. During the overflight, static photos (Fig. 4) and video images of the surface part of the designated study area were taken. The flight altitude was set at 10 meters, chosen based on the camera's resolution and the width of the scanned area. Land leveling effects were not considered due to the study area's small size. The optical assessment revealed that achieving the highest possible photo resolution and accurate image coverage of the study area took precedence over ground leveling (Contreras-de-Villar et al. 2021). The obtained images were evaluated visually and with a segmentation model based on U-Net networks. Prior to image analysis, bitmaps identified during the sand screening process using a solids cleaning machine were uploaded to the system. Visual examination of photos and video files was also carried out to identify any residues that might contaminate the beach sands.

Fig. 2. Location of sample No. 0 collection

a b c d

Fig. 3. (a) Distribution of sampling points for petrographic analysis. (b) Steel quadrat for sampling sands for petrographic analysis. (c,d) Selected polished sections for microscopic observation made of collected beach sands.

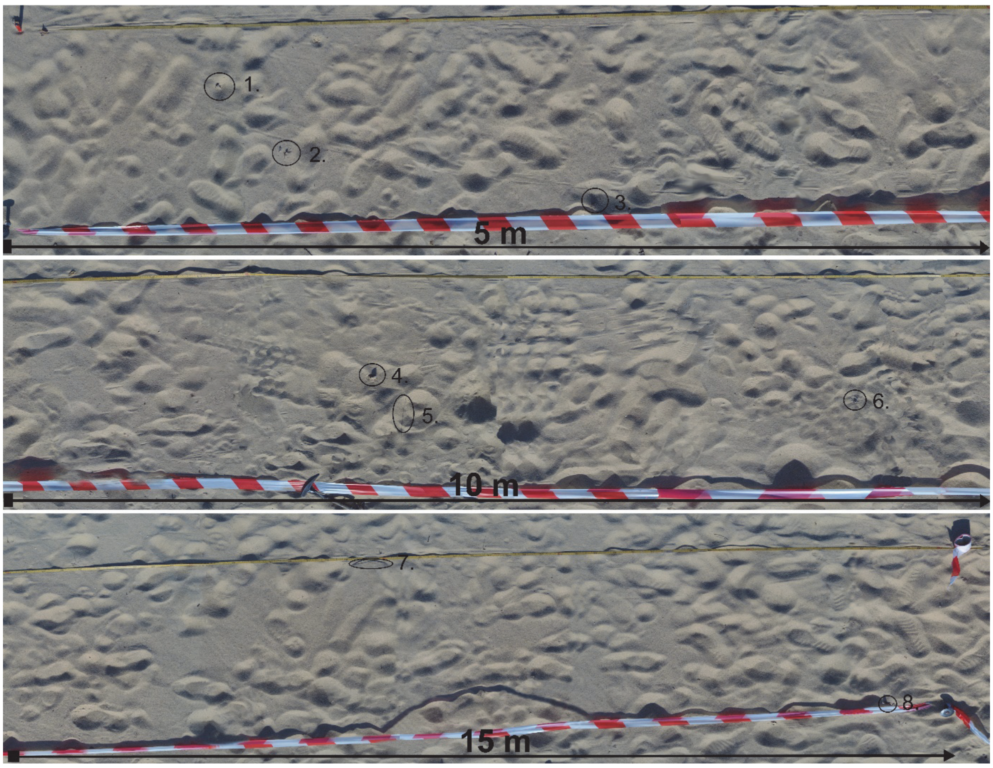


Fig. 4. Mapping of the surveyed area with a drone (1–8, identified waste)

Assessment of solid waste on sandy beaches

A specialized beach sand cleaning machine was used to identify waste deposited in beach sands such as glass, plastics, metals, organic matter (not thermally altered), charcoal, fossil coal, etc. (Fig. 5). The sand from the study area was screened using a sieve mounted in a cleaning machine with a mesh diameter of 1 cm. The sieve diameter was adjusted to match the grain size of beach sands, which ranged from 0.1 to 0.6 cm. This adjustment facilitated the separation of quartz grains and other remaining minerals from waste material. The material for screening was collected by the machine to a depth of about 14 cm. The sand was sieved in three runs, each 15 meters in length and 0.9 meters in with. This process allowed for the sieving of sand from the designated test area, measuring 15 m × 2.7 m.

The material from the sieve (Fig. 6a) was sorted into glass, plastics, paper (cellulose), metals, organic matter (branches, leaves, seeds, and other non-heat-treated plant fragments) and charcoal.

Results and discussion

Petrographic analysis

Petrographic examination of the sand brought in for distributing over the surface (sample No. 0) before the holiday season (Table 1) showed no solids other than mineral matter (sand) and organic matter from the surrounding trees. The sand was brought in November 2020, coincidning with a slight fall of leaves that got mixed with the material prepared for leveling the beach. Another study of the beach sands was conducted in September 2021, after the end of the bathing season. The results obtained from the microscopic analysis of nine samples of beach sands collected showed that, apart from the dominant mineral components in beach sands, other elements were identified in the sands. These included glass, metal, charcoal, fossil coal, plastic, cellulose (paper) and thermally unchanged organic matter. (Fig. 7).

The presence of charcoal in beach sands is related to the thermal processing of food in grill devices. Fragments of charcoal, fossil coals, slags, or ashes are detected only during petrographic analysis. Although, these fragments are mostly small, they can pose a threat to users of recreational facilities despite their limited size. The small size of the charcoal fragments makes them hardly visible, which can lead to choking hazards or the contamination of unprotected food and beverages. Demonstrating the presence of charcoal in a specific location is only possible through petrographic analysis of sands taken from a designated site. This analysis can provide valuable information for site administrators. For example, it can help locate barbecue stands, while prohibiting their use in areas of beaches with the highest density of beachgoers. In addition, the location of grill stands is intended to protect users who are not involved in barbecuing from barbecue fumes (Badyda et al. 2022).

Petrographic analysis of beach sands also shows that their main component is mineral matter, specifically sand (97–99.6%). Conversely, through immersion oil optical petrography analysis, the predominant undesirable components in beach sands of plant origin were identified (0.4–1.8%). Additionally, elements originating from used plastic packaging (0.1–0.4%), paper packaging fragments (0.1–0.6%), charcoal (0.1–0.5%), glass (0.1–0.4%), metals (0.1–0.4%), rust (0.1–0.3%), ash and slag (0.1–0.3%, and fossil coals (0.1–0.2%) were observed. To estimate the degree of sand contamination, the occurrence percentage of these elements and the quantitative content of the identified solid waste are shown (Fig. 8). The results of the study indicate significant variability in the content of solid waste in the beach sands. This variability is important in determining the overall contamination of the beach, encompassing both the entire area and the specific sections allocated for beachgoers.

Charcoal particles were detected in seven samples, numbered 1 through 6, as well as in sample number 9. Additionally, bituminous coal particles were identified in samples 1 and 2. However, in sample No. 1 the identification of charcoal and bituminous coal was difficult due to significant microscopic images similarity between macerals of the inertinite (fusinite) group and charcoal. In the case of sample No. 2, the observed charcoal particles had a characteristic structure and macerals (vitrinite) found only in fossil coals were recognized in stone coal fragments. The above characteristics made it

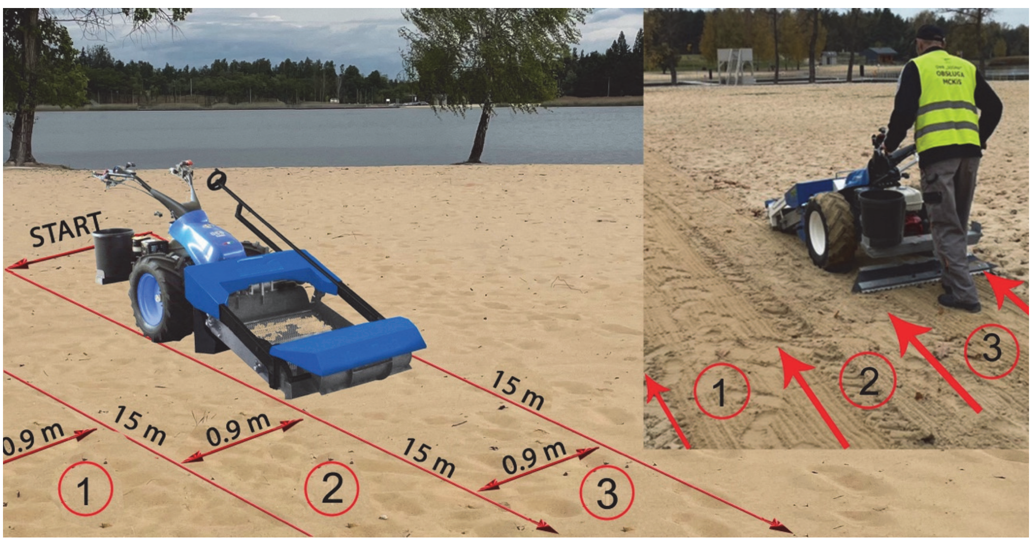


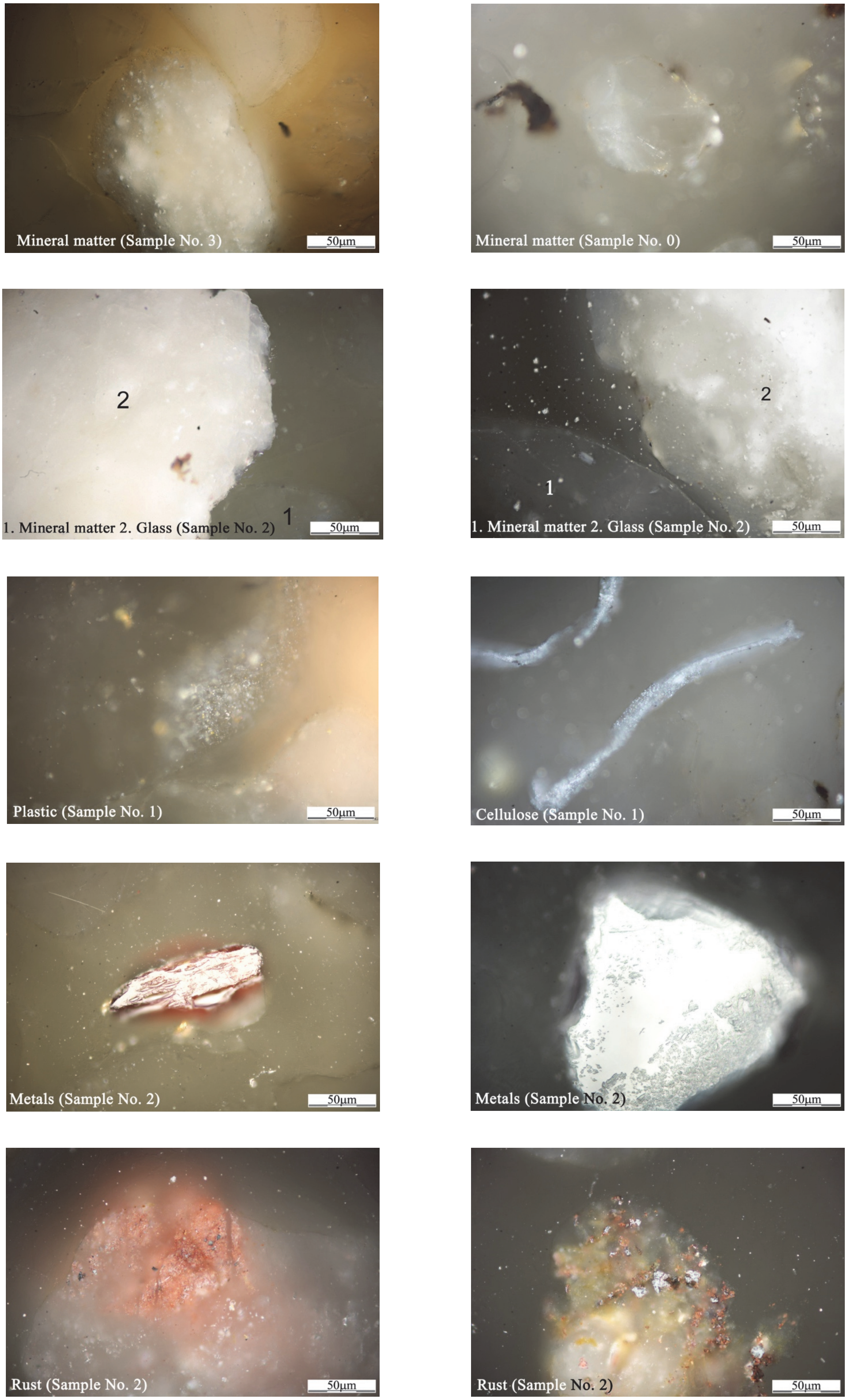
Fig. 5. Beach cleaning machine for solid waste

a

Image	Leafs	Seeds	Others
	*Betula pendula* *Picea* sp.	*Betula pendula*	Coal briquette, seed scales, *Betula pendula* bark frgments, and branches and petioles of *Populus* sp.
	*Betula pendula* (II)	*Betula pendula*	Small *Populus* sp branches, *Betula pendula* bark fragments from
	*Betula pendula*	*Betula pendula*	The fragment of a branch
	Parts of conifer neeedles (II)	N/A	Parts of aquatic plants

b

Fig. 6 (a) – Solid waste revealed in beach sands using a cleaning machine; **(b)** – Biological material identifi ed in beach sands


Mineral matter (Sample No. 3)
50µm
Mineral matter (Sample No. 0)
50µm
2
1
1. Mineral matter 2. Glass (Sample No. 2)
50µm
2
1
1. Mineral matter 2. Glass (Sample No. 2)
50µm
Plastic (Sample No. 1)
50µm
Cellulose (Sample No. 1)
50µm
Metals (Sample No. 2)
50µm
Metals (Sample No. 2)
50µm
Rust (Sample No. 2)
50µm
Rust (Sample No. 2)
50µm

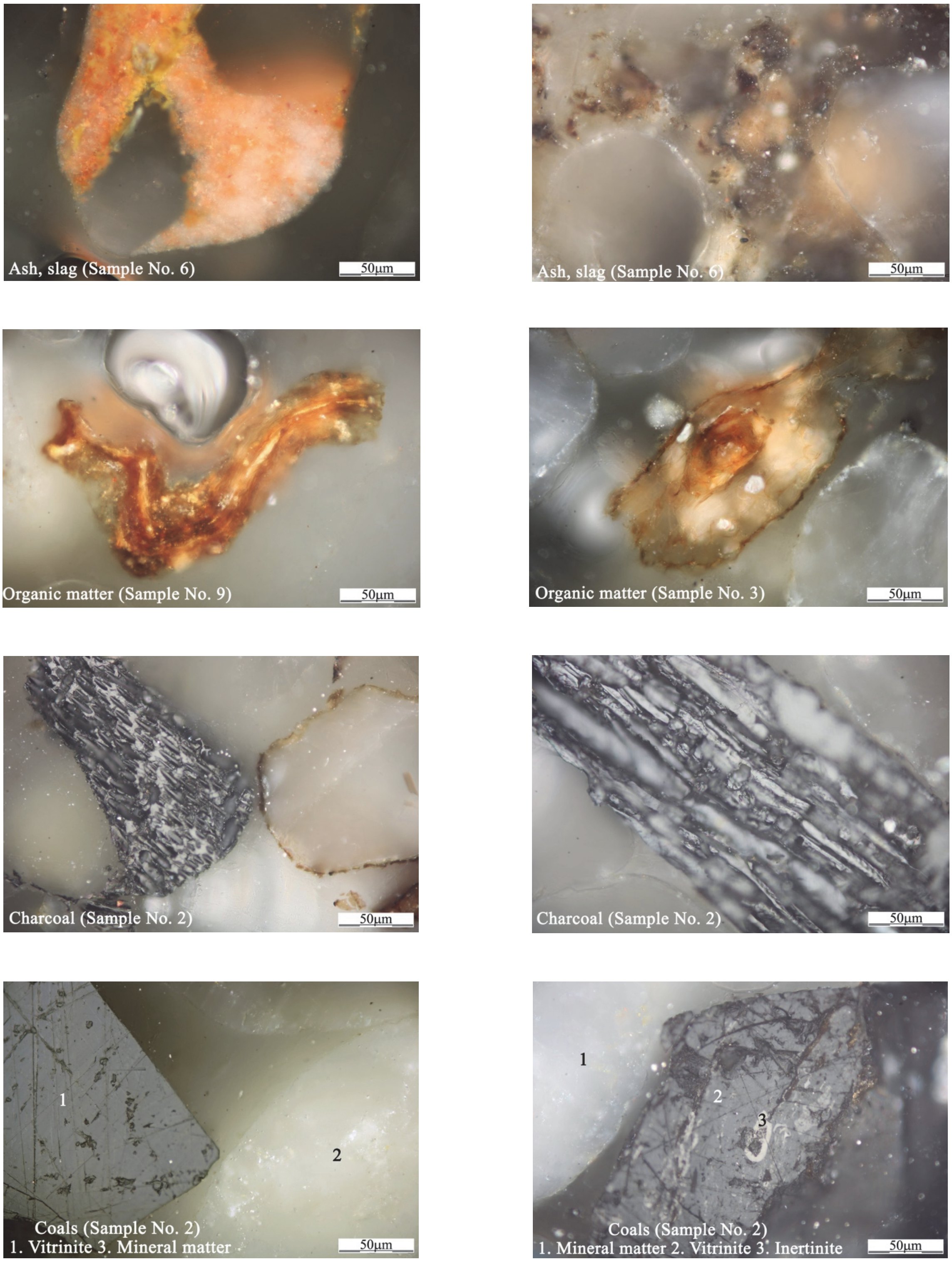


Fig. 7. Microscopic images of solid components of beach sands isolated during petrographic analysis

possible to quantitatively and qualitatively assign the identified waste in the sample within the coals. The determination of the four charcoal particles in sample No. 1 (Fig. 9) , as well as in sample No. 2, was possible thanks to the characteristic structural features that are not present in bituminous coals.

Further microscopic observation of sample No. 1 showed that one of the components exhibited characteristics typical for charcoal particles or particles derived from fossil coal (Fig. 10).

Since resolving the issue of generic contamination of beach sands is of great environmental importance, an effort was undertaken to study distinctions in microscopic imagery between coal (individual fragments from the inertinite group) and charcoal. For the purpose of comparison, microscopic images of the problematic coal were captured under reflected white light using a DIC filter and fluorescence, with oil immersion and charcoal showing similar structural features (Fig. 11).

Comparing images taken under reflected white light, the microscopic examination of charcoal and bituminous coal (a fragment from the inertinite group) reveals certain structural and color similarities, ranging from white to dark grey. The key noticeable difference in the presented microscopic images (Fig. 11A–F) between charcoal and inertinite found in hard coal lies in their preserved structure. In the case of charcoal, sharply defined continuous edges, the absence of cracks, and the uninterrupted cellular structures are evident, creating an impression of a homogeneity. This feature is particularly

Table 1. Solids separated in the studied material based on petrographic analysis

	Sample No. 0		Sample No. 1		Sample No. 2		Sample No. 3		Sample No. 4	
Component	Quantity	%	Quantity	%	Quantity	%	Quantity	%	Quantity	%
Mineral matter	996	99.6	972	97.2	960	96.0	966	96.6	985	98.5
Glass	0	0.0	2	0.2	4	0.4	3	0.3	0	0.0
Plastic	0	0.0	3	0.3	4	0.4	2	0.2	0	0.0
Cellulose	0	0.0	2	0.2	3	0.3	4	0.4	3	0.3
Metals	0	0.0	2	0.2	4	0.4	1	0.1	0	0.0
Rust	0	0.0	1	0.1	3	0.3	2	0.2	0	0.0
Ash, slag	0	0.0	1	0.1	2	0.2	2	0.2	0	0.0
Organic matter	4	0.4	12	1.2	13	1.3	17	1.7	11	1.1
Charcoal	0	0.0	4	0.4	5	0.5	3	0.3	1	0.1
Coals	0	0.0	1	0.1	2	0.2	0	0.0	0	0.0
	100 100		1000 100		1000 100		1000 100		1000 100	
	Sample No. 5		Sample No. 6		Sample No. 7		Sample No. 8		Sample No. 9	
Component	Quantity	%	Quantity	%	Quantity	%	Quantity	%	Quantity	%
Mineral matter	984	98.2	970	97.0	981	98.1	985	98.5	980	98.0
Glass	0	0.0	1	0.1	2	0.2	1	0.1	2	0.2
Plastic	1	0.1	1	0.1	1	0.1	2	0.2	1	0.1
Cellulose	2	0.2	4	0.4	6	0.6	1	0.1	3	0.3
Metals	0	0.0	2	0.2	1	0.1	0	0.0	1	0.1
Rust	0	0.0	0	0.0	0	0.0	0	0.0	2	0.2
Ash, slag	2	0.2	3	0.3	0	0.0	0	0.0	0	0.0
Organic matter	11	1.1	18	1.8	9	0.9	11	1.1	10	1.0
Charcoal	2	0.2	1	0.1	0	0.0	0	0.0	1	0.1
Coals	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
	1000	100	1000	100	1000	100	1000	100	1000	100

* Paper packaging

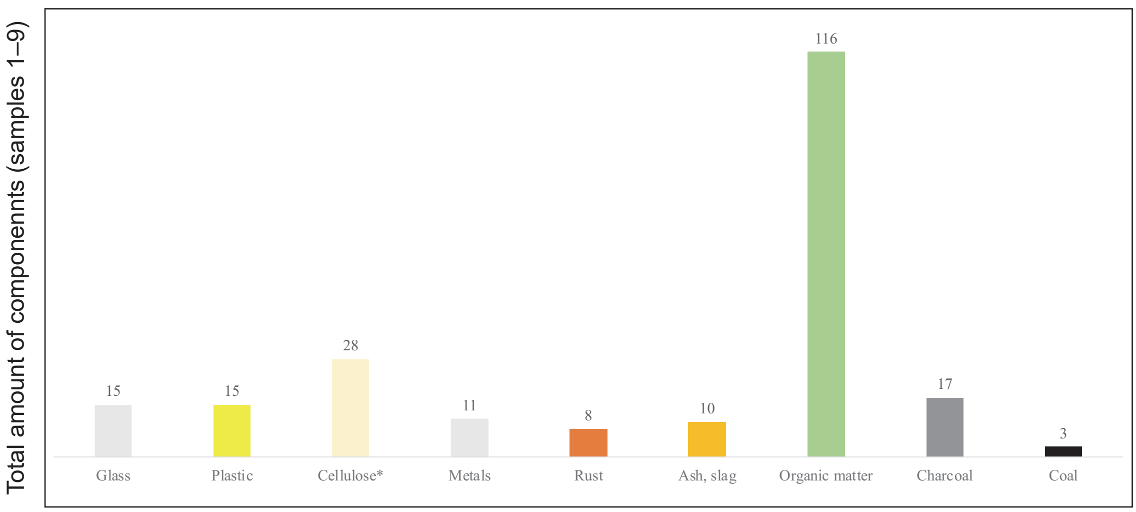


Fig. 8. Summary quantitative distribution of identified solid waste in beach sands based on petrographic analysis

evident in images C and F, where fluorescence reveals less mineral matter in the charcoal structure compared to the fossil coal fragment (Fig. 11F). Furthermore, it is worth noting that a comparison between charcoal and fossil coal fragments showcases the latter's appearance of having undergone not only heat treatment but also substantial pressure. The cells within fossil coal are more flattened, elongated, or clamped and appear to be devoid of fine structures. Conversely, charcoal retains a more complex structure, which is a remnant of the ancient structure of modern wood.

Inertinite present in fossil coal appears more massive and bears the unmistakable characteristics of an organic material that has undergone significant metamorphic transformation. In this case, elevated temperature and pressure cause macro elements constituting the coal to deform, disturbing its original structure. In summary, although charcoal and bituminous coal have similar structures and colors, distinct characteristics visible under the microscope enable their differentiation.

Optical imaging of beach sand surfaces

Thanks to the dynamic advancements in aeronautical techniques, an additional experiment was conducted to evaluate the presence of undesirable components in beach sands using aircraft. Before collecting samples for petrographic research and cleansing the research area using a sand-screening machine, an aerial survey was performed over the designated area. During

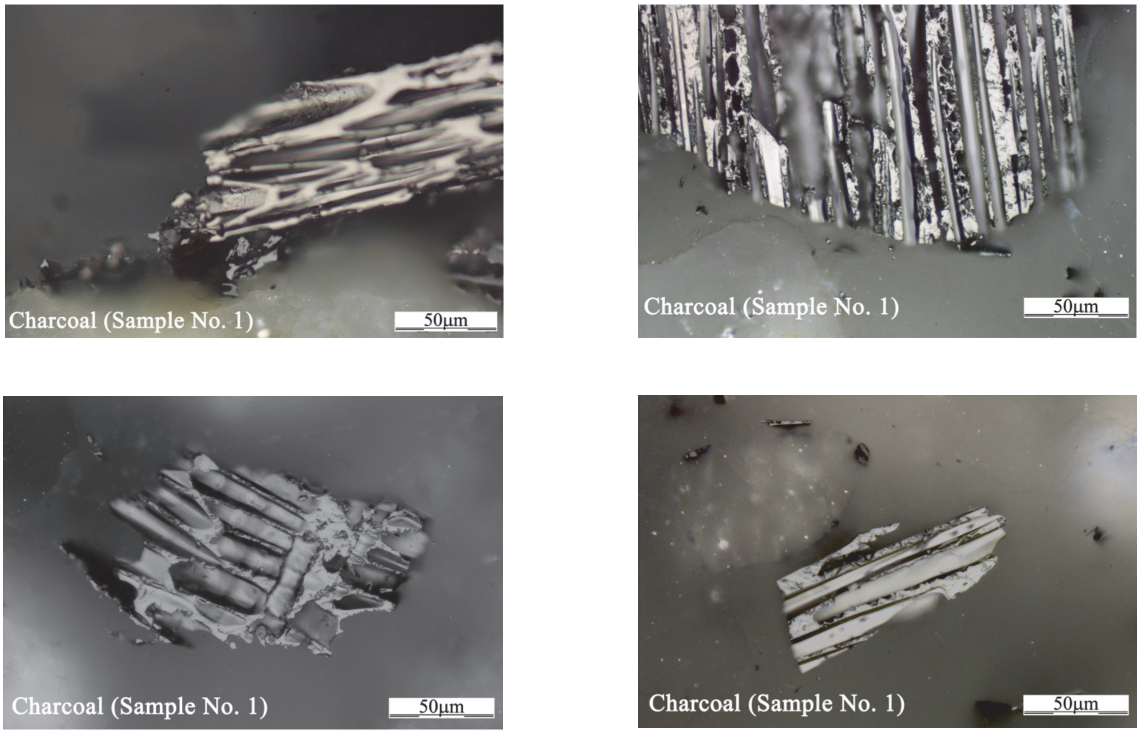


Fig. 9. Microscopic images of charcoal particles (Sample No. 1)

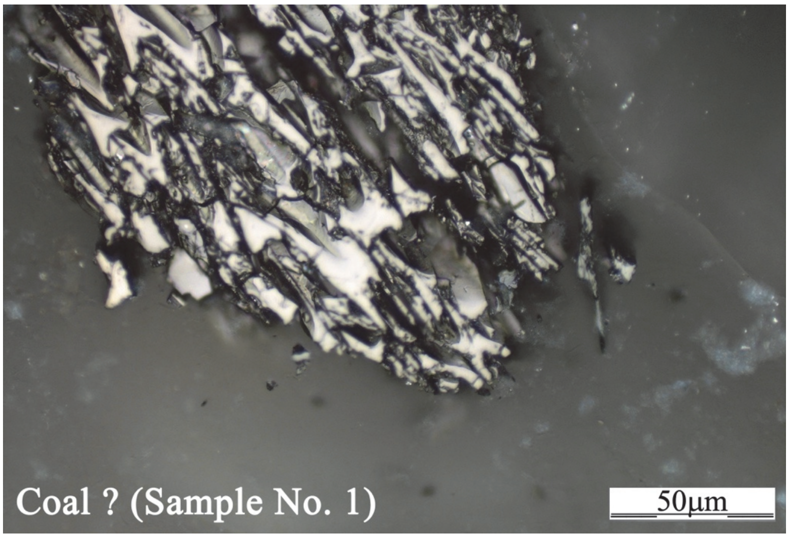


Fig. 10. Microscopic image of particles of coal showing similarity to charcoal and fossil coal during microscopic observation

the flight, static photos were taken, and the surveyed area was filmed, primarily for didactic purposes. While the film served educational intent, the photos were analyzed. However, the results of the optical analysis conducted in this way (Tab. 3) proved to be inadequate in comparison to the results obtained through petrographic analyses. A further attempt at employing neural networks for methodology did not yield reproducible results, so the study resorted to deriving conclusions from optical observations, including the counting of visible elements within the photographic material.

The optical images showed minimal biological elements, such as twigs and leaves throughout the mapped area, suggesting the absence of additional contaminants in observed area. These results stand in contradiction to the data obtained from the petrographic surveys and subsequent insights into contaminant presence in beach sands based on their sieving with a specialized beach cleaner. As the optical imaging method of the beach surface is not useful for the identification of waste, alternative strategies should be employed to assess beach sand contamination. Both drone mapping of the terrain and human-led visual inspection are not sufficient methods for accurately determining waste levels (Table 2).

Assessment of beach sand pollution

The mineral matter was almost entirely separated from other solid components, in the beach sands through sieving with a mesh size of 1 cm, with the exception of three larger rock fragments. In terms of quantity, the main component identified in the beach sands was of biological origin, consisting mainly of leaves, twigs, seeds, etc. from the vegetation growing around the beach. More than 166 different plant fragments were identified, primarily in dried or partially decomposed states. Among the biological materials, fragments from both deciduous and coniferous trees were prevalent, including leaves, needles, and branches. Additionally, a small number of fragments from aquatic plants were observed, likely introduced into the sands

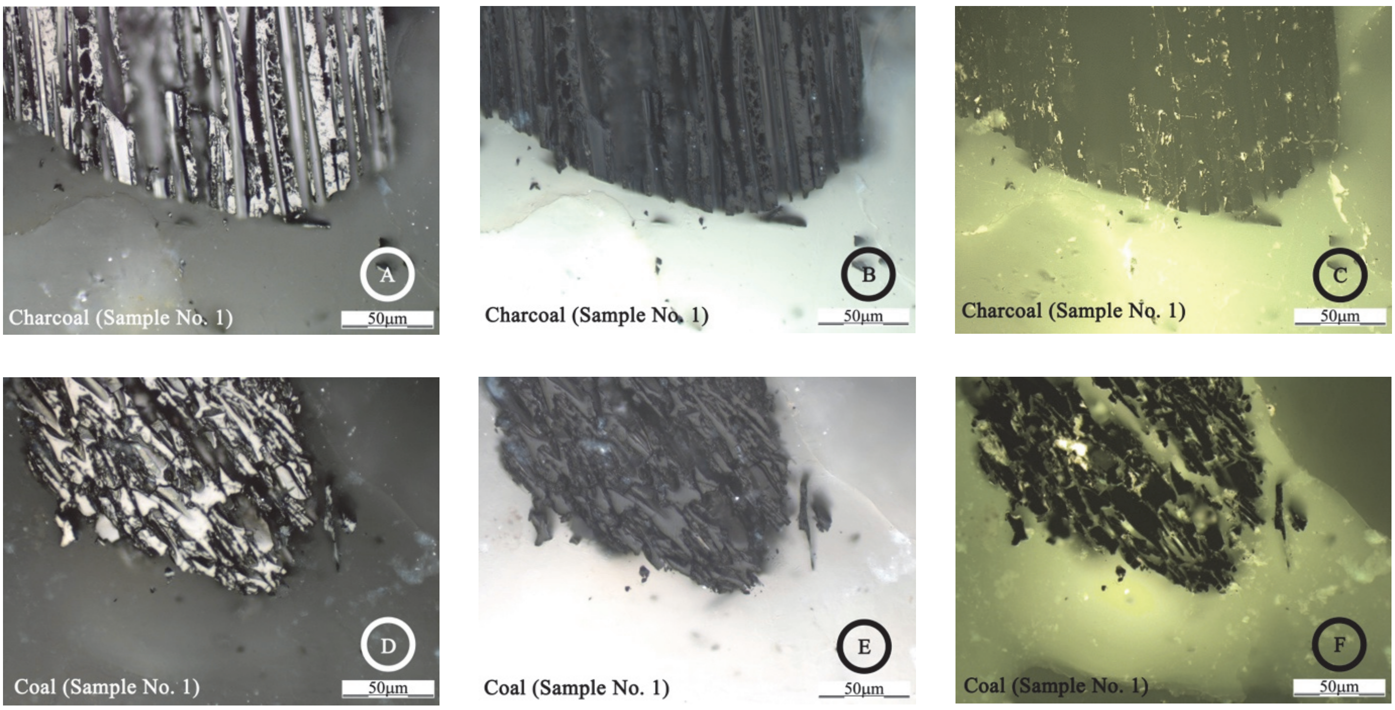


Fig. 11. Comparative comparison of microscopic images of wood charcoal and coal. A and D photographs taken in oil immersion, white reflected light. B and E Images taken in oil immersion, white light reflected using DIC filter. C and F Images taken in oil immersion using fluorescence.

Table 2. Solid waste in beach sands observed during a drone flight over a designated study area

	Lot 1 (15 m × 0.9 m)	Lot 2 (15 m × 0.9 m)	Lot 3 (15 m × 0.9 m)	Total
Component	Amount	Amount	Amount	Amount
Glass	0	0	0	0
Plastic	0	0	0	0
Cellulose	0	0	0	0
Metals	0	0	0	0
Organic matter	8	12	9	29
Charcoal	0	0	0	0
Fossil coal	0	0	0	0

by beachgoers during their activities in the bathing area. Other fairly common waste in the beach sands are cigarette ends, wrapping paper, and plastic packaging. Among the waste, 47 fragments of glass and metal were found, primarily consisting of broken glass, along with 34 metal fragments, mainly caps. The analysis also identified 20 separate charcoal fragments (Table 3).

Both drone-based observation of the beach surface and quantification of individual solids components through screening (excluding mineral matter like sand) and petrographic (quantitative-qualitative analysis) techniques consistently reveal that plant fragments constitute the most abundant contaminant in beach sands. The method of mechanically sieving of sand exposes a significant presence of paper packaging fragments, cigarette butts, plastics, glass, metals, and charcoal. Notably, no rust, ash, slag, or fossil coal were observed (Fig. 12). The mechanical sieving test showed that particles smaller than 1 cm could pass through the sieve. This leads to the conclusion that small particles can only be detected by microscopic analysis (Suárez-Ruiz et al. 2023), which is necessary to get a comprehensive understanding of the undesirable components in beach sands.

Conclusion

The analysis was carried out in the coastal zone of a water reservoir that had been artificially created after the closure of the backfilling sand mine. Analysis of the mapping data from the drone survey of the study area showed that most solid contaminants are not visible during this type of surface scanning. The drone study also highlights the problem of estimating beach contamination solely through visual inspection of the surface, even when executed by staff overseeing such facilities. This is particularly important when the volume of visible beach sand waste is a small, while more hazardous elements such as glass, plastics, metals, charcoal, and substantial amounts of dead plant matter are present.

The comprehensive extent of the qualitative and quantitative contamination present in beach sands has only recently been illuminated through innovative microscopic

Table 3. Fragments of packaging, barbecue fuels, cigarettes, organic matter, etc. waste in beach sands retrieved from a beach cleaner

	1st cleanup (15 m × 0.9 m)	2nd celanup (15 m × 0.9 m)	3rd cleanup (15 m × 0.9 m)	Total
Component	Amount	Amount	Amount	Amount
Glass	19	16	12	47
Plastic	28	31	22	81
Cellulose	38	22	24	84
Metals	16	10	8	34
Organic matter	68	52	46	166
Charcoal	4	9	7	20
Fossil coal	0	0	0	0

* cigarette ends, paper packaging

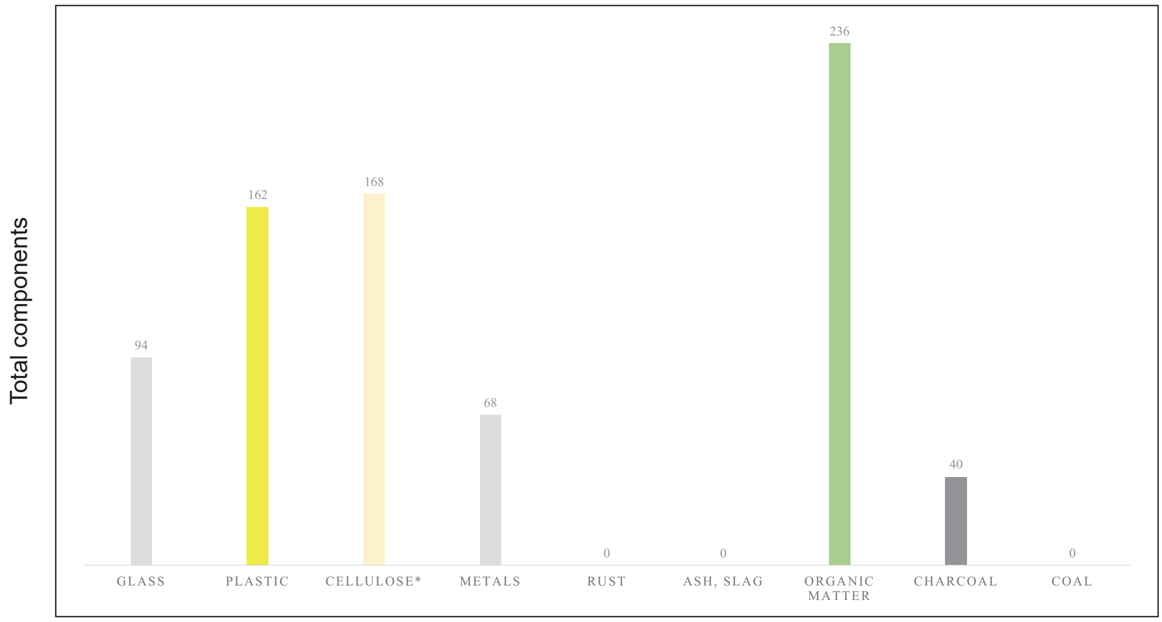


Fig. 12. Quantitative distribution of waste in beach sands based on evaluation of extracted fragments from beach cleaning machine

examination. This notion was further affirmed by a specialized cleaning machine's drainage of the designated beach area to a depth of 14 cm. After a three-month period of beach use, the amount of contamination was relatively low, indicating the low amount of waste generated by beachgoers. The primary contaminants identified were glass, plastics, and metals, however, their shallow deposition depths could potentially pose risks of injury or choking, particularly among children, under unfavorable circumstances.

The beach sands were found to contain fragments of leaves, stems, roots, and branches, fostering an environment conducive to various microorganism growth. While the current epidemiological risk level of contamination in the study area is low, consistent environmental monitoring of regions where plant fragments are prevalent remains an essential measure to ensure epidemiological safety. Regular monitoring of beach sand quality will expedite the identification of potential risk factors, facilitating timely decision-making regarding potential large-scale mechanical cleaning of the entire beach.

The microscopic petrographic analysis of beach sands, as already demonstrated, could potentially emerge as the most effective method for assessing beach contamination levels. To facilitate its successful implementation, the capacity to identify fragments of charcoal and fossil coal has been developed. This identification is of great importance in determining the sources of contamination, especially those stemming from direct human activity, consequently enabling targeted elimination of this waste through administrative measures.

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